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MOLECULAR SIEVE GENERATION OF AVIATOR'S OXYGEN: BREATHING GAS COMPOSITION AS A FUNCTION OF FLOW, INLET PRESSURE, AND CABIN ALTITUDE

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This technical report has been reviewed and is approved for publication.

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The molecular sieve method of generating an enriched-oxygen breathing gas is one of three candidate on-board oxygen generation (OBOG) systems under joint Navy-Air Force development for application in tactical aircraft. As part of this program, the performance of a nominal 2-man-capacity molecular sieve oxygen generation system (MSOG) was characterized under simulated flight conditions. Data were given on the composition (oxygen, nitrogen, carbon dioxide, and argon) of the MSOG-generated breathing gas as a function of inlet air pressure, altitude, and gas flow rate. The maximum oxygen concentration observed

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20. ABSTRACT (Continued)

was 95% with the balance argon. Under certain conditions of pressure, altitude, and flow, the argon enrichment factor exceeded that of oxygen giving a maximum argon concentration of 6.4% with the balance oxygen. The performance of the MSOG was discussed in the context of aircraft operating envelopes using both diluter-demand and 100% delivery subsystems.

MOLECULAR SIEVE GENERATION OF AVIATOR'S OXYGEN: BREATHING GAS COMPOSITION AS A FUNCTION OF FLOW, INLET PRESSURE, AND CABIN ALTITUDE

INTRODUCTION

The concept of in-flight generation of breathing gas, to replace stored supplies of liquid or gaseous oxygen, is particularly attractive for military aircraft, not only to increase systems safety, but also to unburden the aircraft from logistics requirements which severely constrain basing options and can limit mission duration. The molecular sieve method of generating an enriched-oxygen breathing gas is one of three candidate on-board oxygen generation (OBOG) systems under joint Air Force-Navy development for application in tactical aircraft (6). The OBOG process employs engine bleed air as both a pressurized feed gas and source of oxygen. Compared to other OBOG systems, the molecular sieve offers the advantage of low aircraft penalty for weight and power, but the disadvantage of producing less than a 100% oxygen product (2, 5).

This report details the results of tests conducted at the USAF School of Aerospace Medicine to characterize the performance of a nominal 2-man-capacity molecular sieve oxygen generator (MSOG) subsystem under simulated flight conditions. The test program was specifically designed to determine the concentration of oxygen, nitrogen, argon, and carbon dioxide in the product breathing gas as a function of MSOG inlet pressure, flow rate, and cabin altitude (outlet pressure). The concentration data was essential to (a) establish criteria for design of a human compatibility (man-rating) test protocol and (b) determine breathing gas composition limits for animal studies to determine relative decompression hazard of argon.

All the test work described in this report was unmanned and was preliminary to a compatibility evaluation protocol using human test subjects. The latter will be detailed in a subsequent report. The joint Navy-Air Force test plan calls for feasibility demonstration flight test of the 2-man molecular sieve unit in a U.S. Navy EA-6B "Prowler" twin-engine jet aircraft in early 1978. Since follow-on application for a molecular sieve system is tentatively programmed for the USMC AV-8A "Harrier," selected test points from the operating envelope of this aircraft were incorporated in the experimental protocol.

METHODS AND MATERIALS

Molecular Sieve Oxygen Generator

Generator Subsystem--The molecular sieve oxygen generator system (Fig. 1) used in this investigation was manufactured by the Bendix Corporation, Instruments and Life Support Division, Davenport, Iowa. The system was designed to fit the envelope of a standard 10-liter LOX converter and had dimensions of 38 cm long by 30.5 cm wide by 33 cm high. It weighed 13.6 kg (30 lb) and used 45 watts of power from a 28 VDC electrical supply.

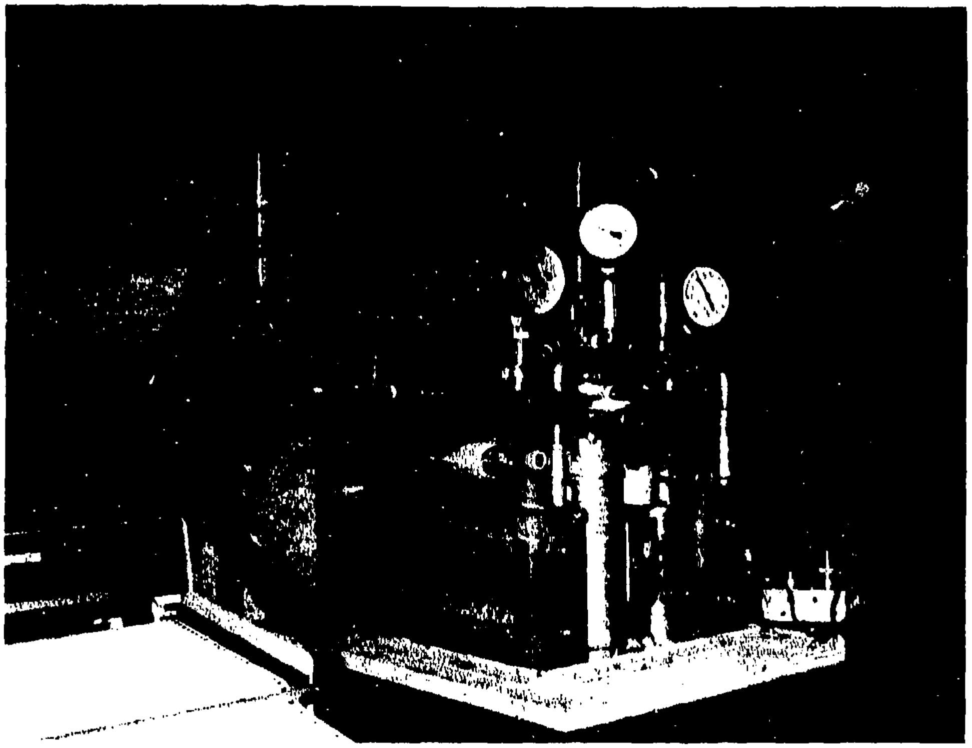

Figure 1. Two-man molecular sieve oxygen generator (MSOG).

A schematic of the Bendix molecular sieve unit is shown in Figure 2. The system utilized a cyclic pressure swing adsorption process with two alternating molecular sieve beds and a gaseous back purge for bed regeneration. Pressured air (from the turbine engine compressor stage or simulation facility) was alternately admitted to the molecular sieve bed through a filter, pressure regulator, and rotating inlet valve. As the pressure front propagated through the bed, the air mixture separated into identifiable constituents as shown schematically in Figure 3. The

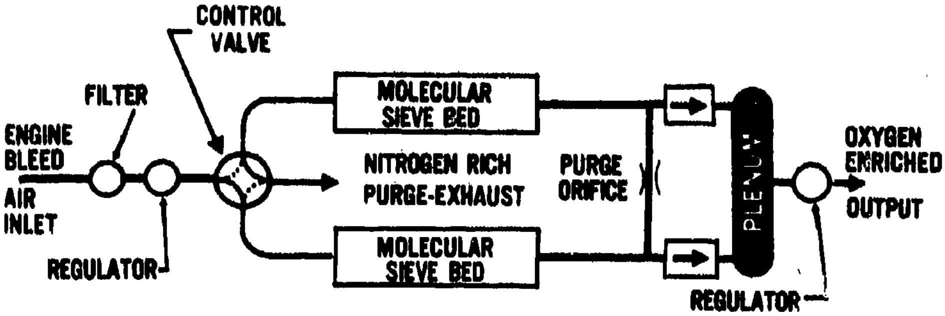

Figure 2. Schematic flow diagram for 2-man molecular sieve oxygen generator.

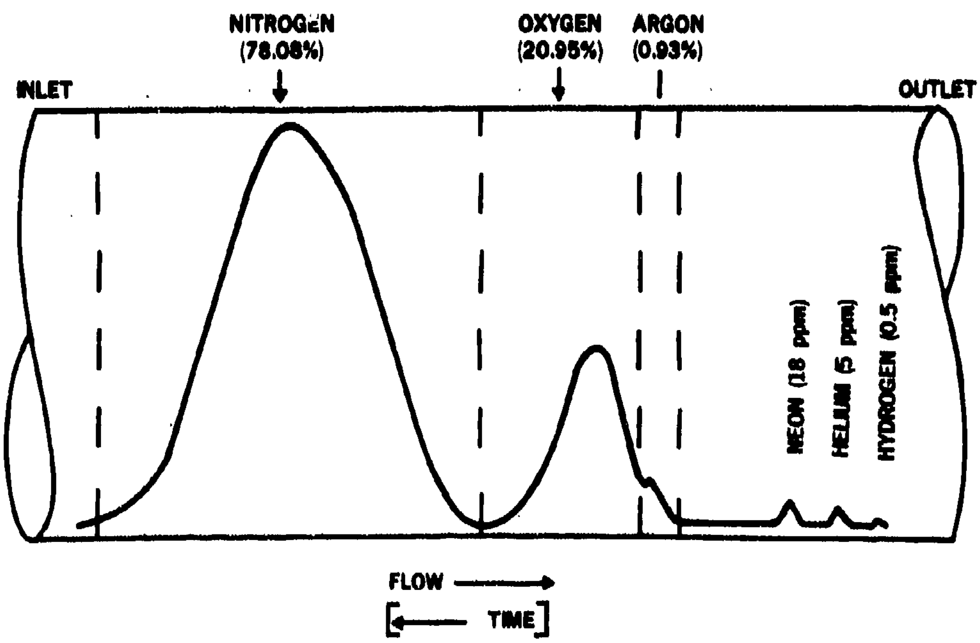

Figure 3. Idealized separation of air on molecular sieve 5A. Numerical values represent normal concentration of ambient air.

oxygen/argon-rich product gas was passed through a check valve and holding plenum (1-liter volume) prior to delivery to the oxygen regulator. A portion of the effluent gas was backflushed through the desorbing bed via a purge control orifice. The exhaust port from the desorbing bed was vented into a chamber maintained at a pre-set (simulated) aircraft altitude. The inlet control valve was rotated at approximately 2.7 rpm which gave a complete sorption/desorption cycle of about 22 sec. Each bed of the MSOG system contained approximately 5 kg (11 lb) of molecular sieve, type 5A, in pellet form. The internal pressure regulator was set to provide a constant 5.1 ATA (60 psig) to the bed when the air supply pressure was greater than 5.1 ATA. The internal regulator became fully opened below about 5.1 ATA (60 psig) and delivered essentially the same as the inlet pressure between 5.1 ATA and 1.0 ATA (0 psig).

Molecular Sieve Sorbent--Chemically, molecular sieves are crystalline aluminosilicate compounds called zeolites with the general formula $MN_2O-Al_2O-nSiO_2-mH_2O$, where M is calcium, strontium, or barium, and N is either sodium or potassium (1). The ability of molecular sieve to separate gaseous mixtures into components is based primarily on the porous structure of the zeolite crystal. The highly uniform pores, with dimensions in the molecular range, are formed by heating the fresh zeolite which thereby loses its water of hydration and undergoes lattice shrinkage. The pore size of synthetic molecular sieves can be adjusted by varying the concentration of alkali metals in the crystal. Because of their chemical properties and structure, molecular sieves will separate complex gas mixtures based not only on the physical dimensions of the constituent molecules, but also on their polarity. Hence, large, polar molecules are retained on molecular sieve while smaller and less polar molecules are not. Since the retained molecules are held by Van der Waals (adsorptive) forces rather than chemical bonding, the process can be reversed by fairly mild changes in pressure or temperature.

Figure 3 shows an idealized separation of air by a bed (tube/pipe) of molecular sieve, type 5A. With a hypothetical carrier gas, the lighter molecules, including hydrogen, helium, and neon elute first, followed by argon, oxygen, and nitrogen, in that order. For these nonpolar constituents the separation is due entirely to molecular size. Since argon and oxygen have almost the same molecular dimensions, they elute as a single peak which results in a maximum oxygen concentration of approximately 95% with the balance argon.

Chamber Setup

The experimental setup is shown schematically in Figure 4. The molecular sieve system (Fig. 5) was set up to evaluate its performance under flight-simulated conditions as much as possible. Two altitude chambers were employed, one to simulate aircraft altitude and the other to simulate cabin altitude. The aircraft chamber received the nitrogen-rich exhaust gas from the molecular sieve and the cabin chamber received the oxygen-rich breathing gas. Each chamber contained a volume of

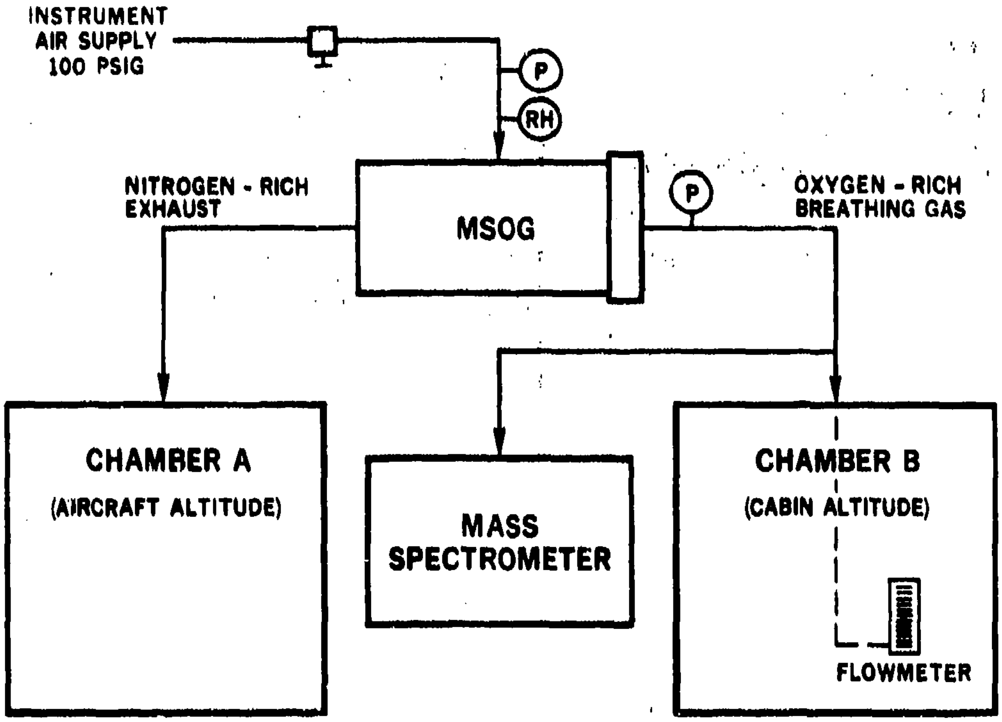

Figure 4. Schematic of test setup.

8.3 m^3 and was maintained at altitude with up to four 11 kW (15-horsepower) vacuum pumps (Nash Model H-5). Each vacuum pump had a capacity of 3.6 m^3/min (130 CFM) at 12.2 km (40,000 ft) altitude. The air supply to the molecular sieve was 7.8 ATA (100 psig) instrument air pumped by a water-sealed compressor and dried to a dew point of -14°C by a refrigeration drier. Inlet air pressure to the molecular sieve itself was adjusted by a diaphragm regulator. The pressure and dew point of the process air were monitored by indicators located upstream of the molecular sieve unit.

The molecular sieve effluent (breathing gas) composition was monitored continuously by a respiratory mass spectrometer (Perkin-Elmer Model MGA-1100) as shown in Figure 5. The mass spectrometer measured four constituents simultaneously: oxygen (mass 32), nitrogen (mass 28), carbon dioxide (mass 44), and argon (mass 40). The output from each channel was continuously recorded on two 2-channel strip-chart recorders. The sampling rate to the mass spectrometer was 60 cm^3/min.

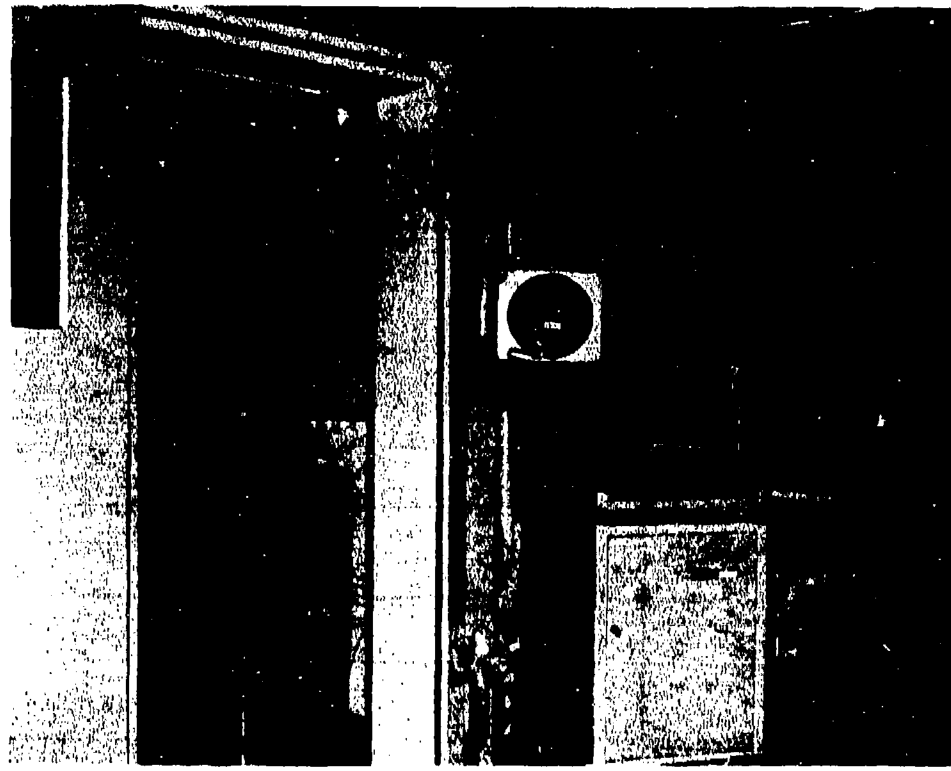

Figure 5. Photograph of test setup: molecular sieve unit is in the background next to exhaust chamber; cabin altitude chamber with flowmeter in place is in the foreground.

Experimental Protocol

The objective of the test program was to determine composition of the molecular sieve product gas (oxygen, nitrogen, carbon dioxide, and argon) as a function of inlet pressure, altitude, and flow rate. The experimental protocol is shown in Table 1 and involved essentially a three-dimensional matrix. The steady-state product gas composition was measured at each pressure and flow rate, and at selected aircraft/cabin altitude combinations simulating real world conditions. For example, at an aircraft altitude of 6.1 km (20,000 ft), the cabin altitudes selected were 2.4 km (8,000 ft) simulating EA-6B pressurization schedule, 3.7 km (12,000 ft) simulating AV-8A cabin pressurization schedule, and 6.1 km (20,000 ft) simulating a decompression. The cabin pressurization schedules for the two aircraft and the altitude test points are shown in Figure 6. The flow rate at each cabin altitude was set at the five values specified in Table 1 at each cabin altitude. Owing to dry gas expansion, mass flow rate was greatest at ground level and decreased progressively with cabin altitude.

TABLE 1. INDEPENDENT VARIABLES FOR DETERMINATION OF MOLECULAR SIEVE PRODUCT GAS COMPOSITION

Supply air pressure ATA (psig)	Aircraft altitude km (kft)	Cabin altitude km (kft)	Product gas flow rate liters/min
1.5 (8)	GL	GL	13.1
2.0 (15)	3.0 (10.0)	2.3 (7.5)	26.2
2.7 (25)	6.1 (20.0)	2.4 (8.0), 3.7 (12.0), 6.1 (20.0)	39.3
3.7 (40)	9.1 (30.0)	3.7 (12.0), 4.9 (16.0), 9.1 (30.0)	52.4
5.1 (60)	12.2 (40.0)	5.0 (16.5), 6.7 (22.0), 12.2 (40.0)	78.6
	13.4 (44.0)	5.5 (18.0), 13.4 (44.0)	

RESULTS AND DISCUSSION

The oxygen content of the molecular sieve product gas is shown in Figures 7, 8, and 9 as a function of cabin altitude, flow rate, and pressure, respectively. The detailed numerical data are given in the Appendix. The maximum oxygen concentration observed was 95.0% obtained at flow rates up to 39.3 lpm with the aircraft and cabin altitudes both 9.1 km (30,000 ft) or above, and the inlet pressure 2.7 ATA (25 psig) or greater. The maximum argon concentration observed was 6.4% (Fig. 10), obtained at flow rate of 13.1 lpm, with a cabin/aircraft altitude combination of 3.7/6.1 km (12,000/20,000 ft), and an inlet pressure of 3.7 ATA (40 psig) or greater. In general, oxygen concentration from the molecular sieve was a strong function of mass flow; i.e., oxygen concentration increased (up to a maximum of 95% O_2) with inlet pressure and cabin altitude, and decreased with volumetric flow. At all cabin altitudes above 9.1 km (30,000 ft), the oxygen concentration remained in the range from 94% to 95%, at all flows up 78.6 lpm and all inlet pressures down to 2.5 ATA (15 psig). At an inlet pressure of 1.5 ATA (8 psig), the oxygen concentration dropped below 94% only at flows above 39.3 lpm.

The application envelope for the present molecular sieve unit is somewhat dependent on the type of delivery subsystem employed. With a conventional air-mix (diluter-demand) regulator, for example, the molecular sieve delivered adequate oxygen (as defined by MIL-R-83178) at all altitudes up to 9.8 km (32,000 ft) as long as the inlet air pressure was

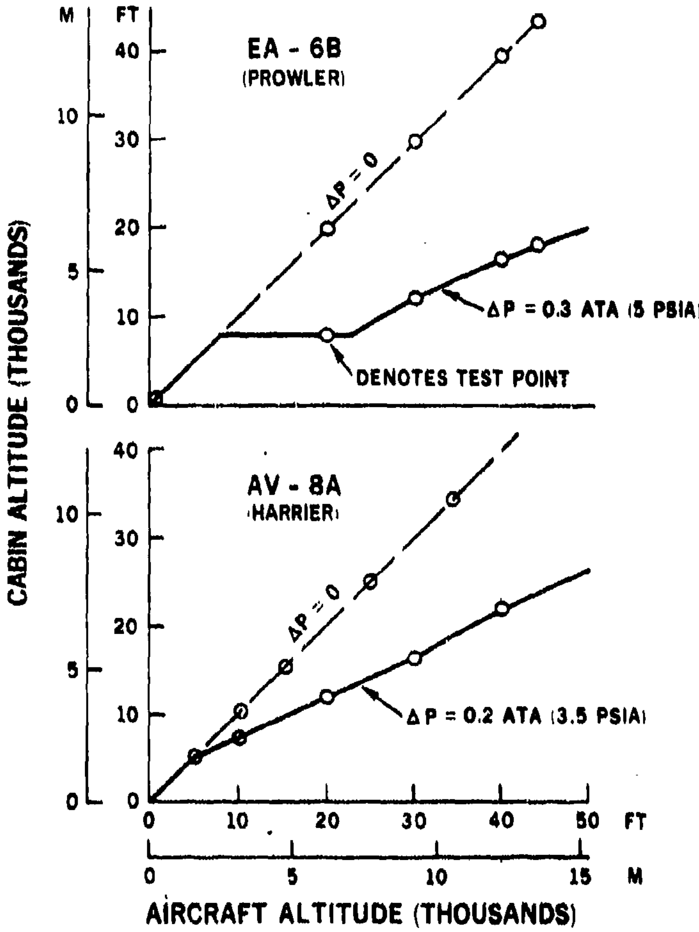

Figure 6. Pressurization schedule--cabin altitude vs. aircraft altitude for EA-6B "Prowler" and AV-8A "Harrier."

greater than about 2.0 ATA (15 psig) and flow was less than 26 liters/min per man (Fig. 7). The recent data of Morgan et al. (3, 4) indicate that for most pilot activities, the upper bound on minute ventilation rate is about 30 liters/min per man; hence, this restriction on the molecular sieve unit is not severe. In the 100% delivery mode, however, the envelope is somewhat more restrictive. In this case, the critical parameter was gas availability rather than oxygen concentration, and gas flow was adequate at all altitudes only when the inlet pressure was 2.7 ATA (25 psig) or greater. When inlet pressure was less than 2.7 ATA, the gas availability was a function of flow and altitude as shown by the curve termination points in Figures 7 and 8.

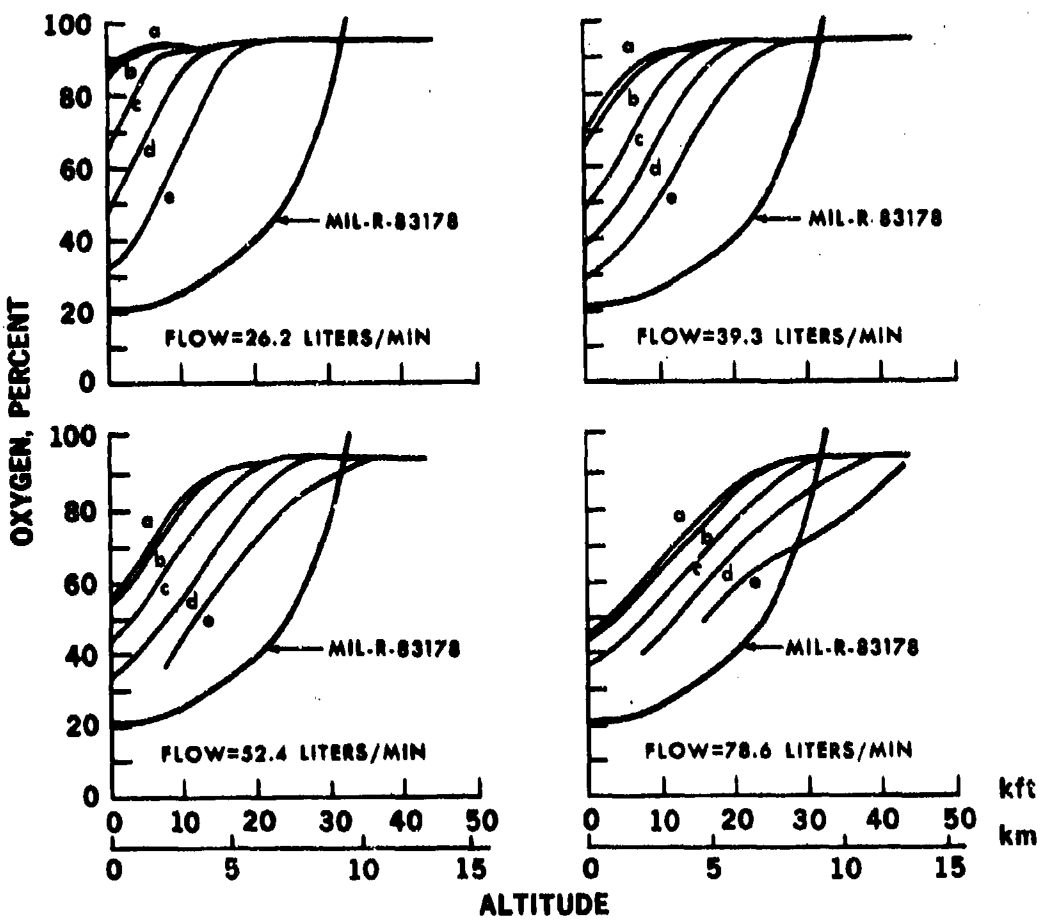

Figure 7. Molecular sieve product oxygen concentration vs. cabin altitude at constant flow. Parameter in MSOG inlet pressure: a is 5.1 ATA (60 psig); b is 3.7 ATA (40 psig); c is 2.7 ATA (25 psig); d is 2.0 ATA (15 psig); and e is 1.5 ATA (8 psig).

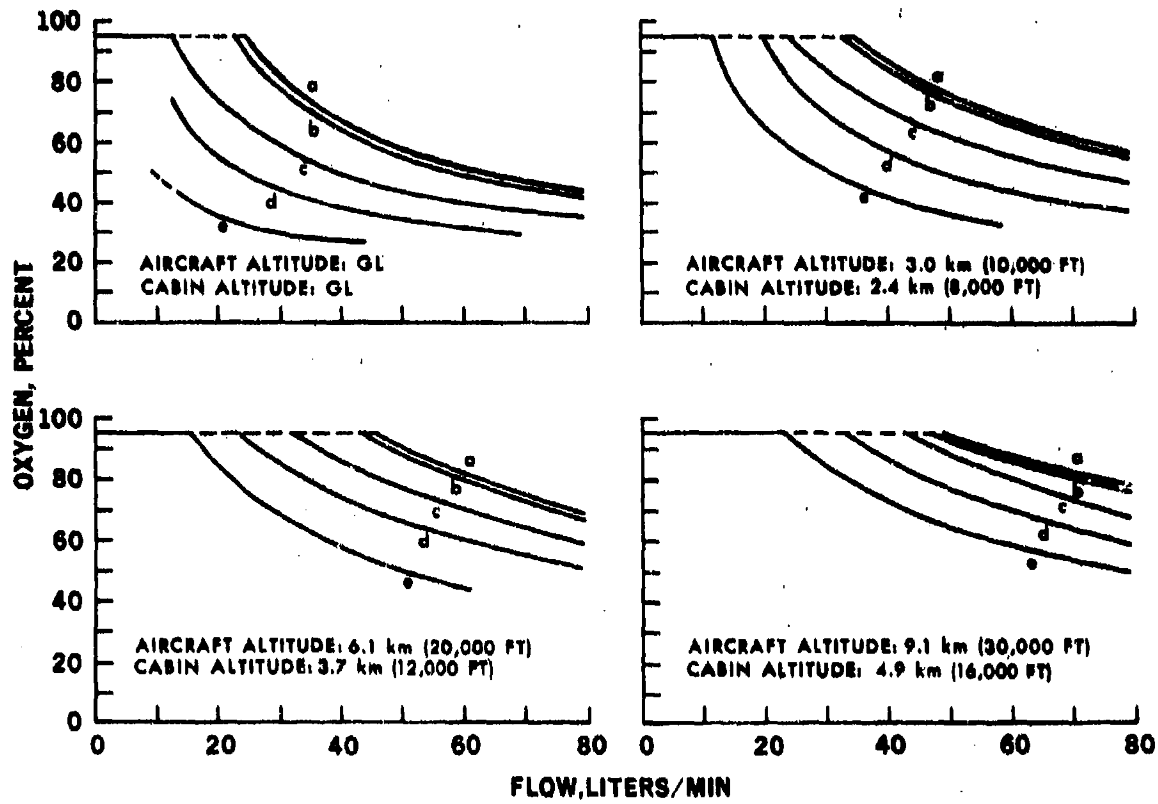

Figure 8. Molecular sieve product oxygen concentration vs. flow at constant cabin altitude. Parameter is MSOG inlet pressure: a is 5.1 ATA (60 psig); b is 3.7 ATA (40 psig); c is 2.7 ATA (25 psig); d is 2.0 ATA (15 psig); and e is 1.5 ATA (8 psig).

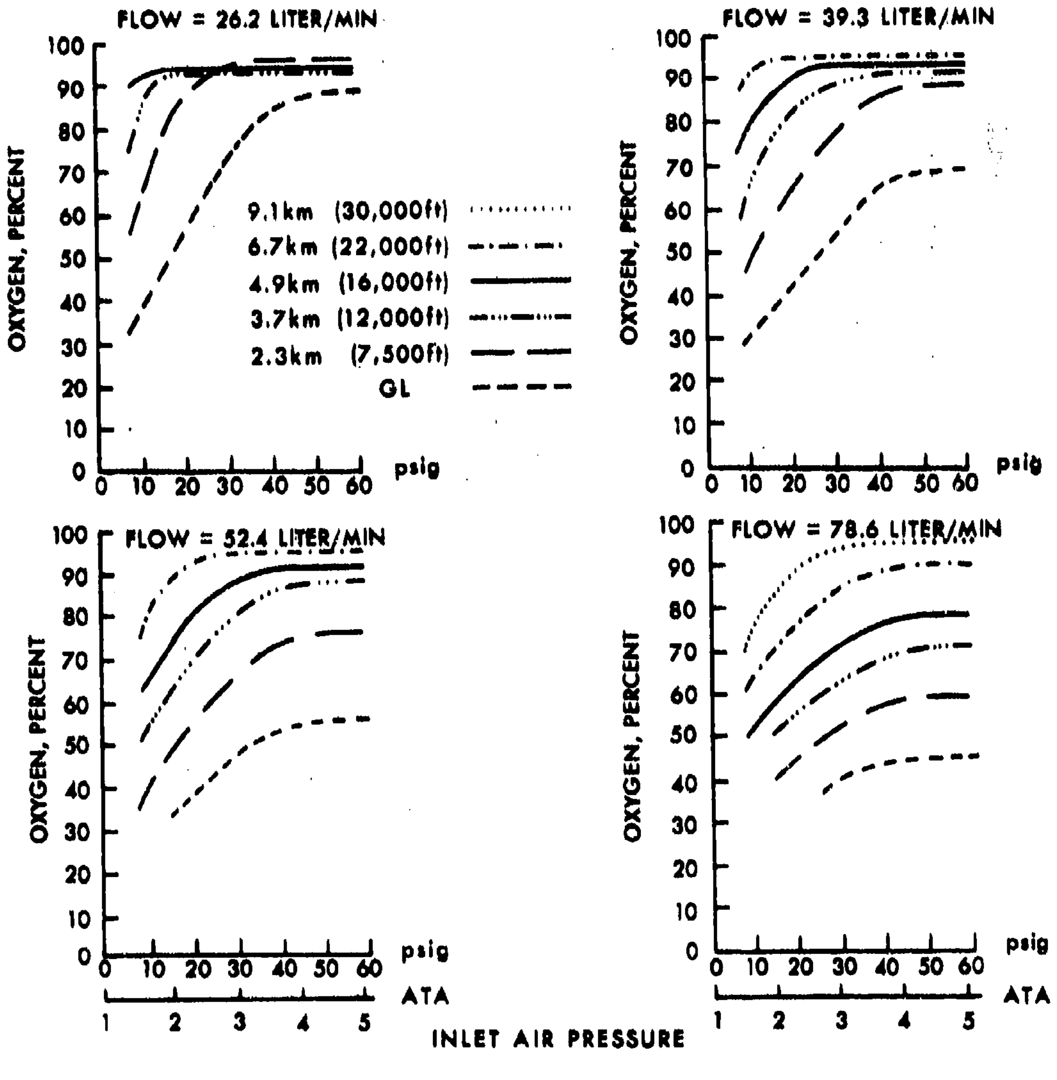

Figure 9. Molecular sieve product oxygen concentration vs. inlet air pressure at constant flow. Parameter is cabin altitude.

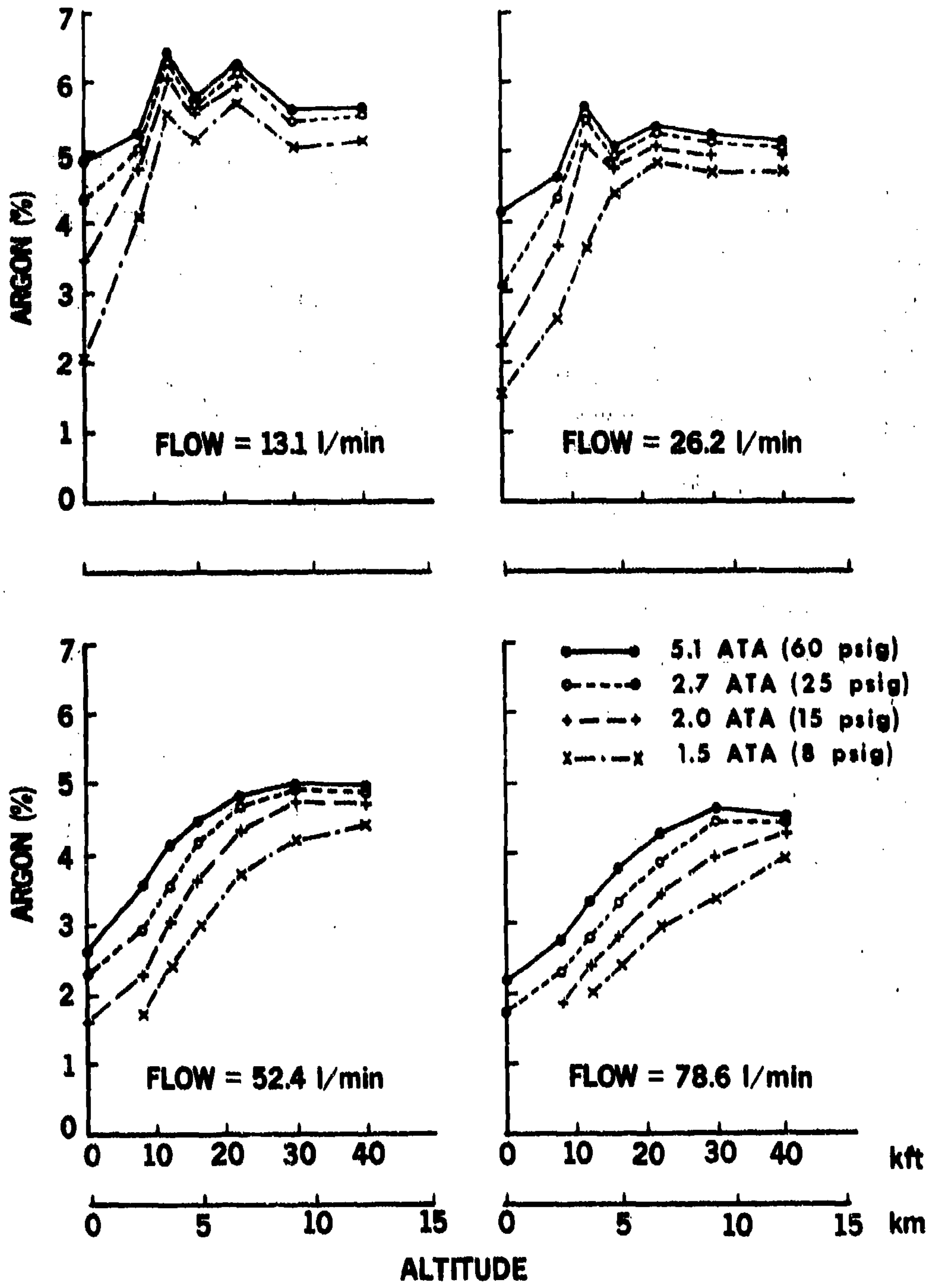

Figure 10. Molecular sieve product argon concentration vs. altitude at constant flow. Parameter is MSOG inlet pressure.

In summary, the molecular sieve unit provided adequate oxygen for hypoxia protection at nominal use rates up to a cabin altitude of approximately 9.8 km (32,000 ft). With appropriate modification of associated delivery equipment (to account for pressure breathing of less than a 100% oxygen mixture), the altitude ceiling can doubtless be increased to 12.2 km (40,000 ft) or higher. Effluent argon concentrations from the MSOG measured from 2.0% to about 6.4%. At these concentration levels, it is considered unlikely that argon will present any significant risk of decompression sickness. Animal studies are currently on-going at the USAF School of Aerospace Medicine using a Doppler technique to determine the number of intravascular bubbles formed with 100% oxygen, and with breathing gas mixtures containing either argon or nitrogen as diluent. These studies will provide an index of the relative risk of decompression sickness resulting from breathing molecular sieve-generated oxygen.

The primary deficiencies of the molecular sieve unit were the decrease in oxygen concentration with flow rate and, perhaps more importantly, the limitation in gas flow at reduced inlet pressure. The latter poses a unique operational problem with molecular sieves in that low MSOG inlet pressure may obtain during a descent from high altitude under reduced engine power; i.e., the "idle let down" situation. The combination of factors reinforces an altitude limit on the application of molecular sieve oxygen units in aircraft without some form of pressure augmentation. One way to circumvent this problem is to limit the idle power setting on the aircraft throttle to maintain an acceptable bleed air pressure. Alternative strategies involve either pressure augmentation of engine bleed air by mechanical compression, or programming the molecular sieve oxygen system to generate only when the bleed air pressure is high and then into a breathing gas accumulator. All of these operational concepts need further development, test and evaluation before final application of a molecular sieve oxygen generating unit can be made.

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APPENDIX

MOLECULAR SIEVE PRODUCT GAS COMPOSITION

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
8	0	0	13.1	43.25	54.45	2.06	0.00
			26.2	32.20	66.15	1.51	0.01
			39.3	28.45	70.25	1.34	0.01
			44.0 Max	27.45	71.30	1.26	0.00
8	5	5	13.1	61.05	35.08	2.90	0.00
			26.2	41.40	55.05	1.96	0.00
			39.3	34.55	63.80	1.63	0.00
			52.4	31.05	67.30	1.43	0.00
			54.8 Max	30.40	68.05	1.39	0.00
8	7.5	10	13.1	85.50	10.60	4.05	0.00
			26.2	54.75	42.80	2.58	0.01
			39.3	43.90	54.00	2.04	0.01
			52.4	36.90	61.30	1.72	0.00
			55.2 Max	34.75	63.75	1.61	0.00
8	8	20	13.1	93.95	1.85	4.55	0.01
			26.2	67.55	29.35	3.21	0.00
			39.3	53.30	44.30	2.51	0.00
			52.4	47.35	50.50	2.20	0.00
			54.5 Max	44.90	52.90	2.14	0.00
8	12	20	13.1	92.55	2.10	5.57	0.00
			26.2	73.80	22.85	3.63	0.00
			39.3	58.55	39.05	2.84	0.00
			52.4	51.80	46.25	2.40	0.00
			76.5 Max	43.30	54.75	2.01	0.00
8	12	30	13.1	93.75	0.80	5.76	0.01
			26.2	83.00	13.40	4.09	0.01
			39.3	66.60	30.45	3.24	0.01
			52.4	57.75	39.80	2.68	0.00
			65.2 Max	50.80	47.00	2.36	0.00
8	16	30	13.1	93.55	1.60	5.19	0.01
			26.2	89.25	6.65	4.38	0.01
			39.3	73.65	22.80	3.58	0.00
			52.4	62.05	35.35	2.99	0.00
			78.6	49.85	47.80	2.37	0.00

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
8	16.5	40	13.1	94.65	0.40	5.36	0.01
			26.2	91.95	3.80	4.56	0.01
			39.3	78.05	18.35	3.80	0.01
			52.4	66.45	30.35	3.22	0.00
			78.6	52.50	45.30	2.49	0.00
8	18	44	13.1	93.95	1.05	5.29	0.01
			26.2	92.90	2.80	4.57	0.01
			39.3	81.05	15.15	3.90	0.01
			52.4	69.35	27.50	3.31	0.01
			78.6	54.45	43.30	2.60	0.00
8	20	20	13.1	92.45	2.80	4.96	0.00
			26.2	86.85	9.10	4.18	0.00
			39.3	69.40	27.55	3.32	0.00
			52.4	59.15	38.00	2.81	0.00
			78.6	46.50	51.45	2.19	0.00
8	22	40	13.1	94.55	0.00	5.74	0.01
			26.2	95.05	0.35	4.85	0.01
			39.3	88.10	7.70	4.31	0.01
			52.4	76.55	19.95	3.73	0.00
			78.6	61.40	35.80	3.94	0.00
8	30	30	13.1				
			26.1	95.15	0.10	5.06	0.01
			39.3	94.60	1.05	4.69	0.01
			52.4	87.60	7.90	4.22	0.01
			78.6	69.95	26.90	3.31	0.00
8	40	40	13.1				
			26.2	95.00	0.20	5.17	0.00
			39.3	95.00	0.20	5.03	0.00
			52.4	95.00	0.20	4.80	0.00
			78.6	88.30	7.20	4.30	0.00
8	44[1]	44[1]	13.1				
			26.2	95.00	0.20	5.51	0.00
			39.3	94.80	0.40	4.96	0.00
			52.4	94.00	1.10	4.85	0.00
			78.6	90.40	5.20	4.43	0.00

[1]Chambers equilibrated at 42,500 ft maximum.

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
15	0	0	13.1	72.05	24.06	3.43	0.00
			26.2	46.90	51.05	2.22	0.00
			39.3	38.60	60.00	1.81	0.00
			52.4	33.90	64.65	1.58	0.00
			69 Max	30.95	67.75	1.43	0.00
15	5	5	13.1	92.50	3.30	4.46	0.01
			26.2	60.20	37.10	2.86	0.00
			39.3	48.80	49.05	2.31	0.00
			52.4	41.00	56.85	1.90	0.00
			78.6	34.30	64.00	1.57	0.00
15	7.5	10	13.1	94.90	0.65	4.74	0.00
			26.2	77.10	19.30	3.64	0.00
			39.3	58.65	38.30	2.77	0.00
			52.4	48.70	49.10	2.27	0.00
			78.6	40.20	58.35	1.86	0.00
15	8	20	13.1	94.95	0.45	4.94	0.01
			26.2	85.35	10.80	4.04	0.01
			39.3	66.60	30.05	3.15	0.00
			52.4	58.60	38.70	2.76	0.00
			78.6	46.45	51.70	2.15	0.00
15	12	20	13.1	92.70	1.50	6.04	0.00
			26.2	90.65	4.50	5.09	0.00
			39.3	76.15	20.25	3.71	0.00
			52.4	64.20	32.95	3.00	0.01
			78.6	51.45	45.95	2.41	0.00
15	12	30	13.1	93.45	0.70	6.09	0.01
			26.2	92.25	3.00	5.13	0.01
			39.3	80.20	16.10	3.90	0.01
			52.4	68.40	28.50	3.21	0.01
			78.6	54.35	43.10	2.55	0.00
15	16	30	13.1	93.30	1.50	5.56	0.01
			26.2	93.40	2.05	4.74	0.01
			39.3	86.70	9.30	4.23	0.01
			52.4	73.90	22.85	3.59	0.00
			78.6	58.85	38.40	2.81	0.00

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
15	16.5	40	13.1	94.35	0.30	5.59	0.00
			26.2	94.45	1.00	4.77	0.00
			39.3	89.95	6.15	4.33	0.00
			52.4	77.50	19.00	3.71	0.00
			78.6	60.80	36.55	2.90	0.00
15	18	44	13.1	93.65	0.90	5.71	0.01
			26.2	94.25	1.15	4.84	0.01
			39.3	92.10	3.70	4.50	0.01
			52.4	82.00	14.20	3.95	0.01
			78.6	62.85	34.30	3.02	0.00
15	20	20	13.1	91.45	3.35	5.43	0.00
			26.2	91.95	3.75	4.61	0.00
			39.3	86.60	9.55	4.14	0.00
			52.4	74.30	22.30	3.54	0.00
			78.6	56.80	40.55	2.71	0.00
15	22	40	13.1	94.05	0.10	6.16	0.01
			26.2	95.15	0.10	5.08	0.01
			39.3	94.35	1.25	4.71	0.01
			52.4	88.15	7.75	4.30	0.01
			78.6	70.70	26.05	3.40	0.01
15	30	30	13.1				
			26.2	94.70	0.20	5.40	0.00
			39.3	95.00	0.30	4.94	0.00
			52.4	94.50	1.15	4.67	0.00
			78.6	83.35	12.80	3.95	0.01
15	40	40	13.1				
			26.2	94.90	0.30	5.56	0.00
			39.3	94.80	0.40	5.18	0.00
			52.4	94.50	0.50	5.31	0.00
			78.6	94.50	0.50	4.68	0.00
15	44[1]	44[1]	13.1				
			26.2	95.00	0.10	5.84	0.00
			39.3	95.00	0.10	5.19	0.00
			52.4	95.00	0.30	5.02	0.00
			78.6	95.00	0.50	4.70	0.00

[1] Chambers equilibrated at 42,500 ft maximum.

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
25	0	0	13.1	92.90	2.90	4.30	0.01
			26.2	63.95	33.45	3.02	0.00
			39.3	48.50	48.70	2.32	0.00
			52.4	43.55	53.95	2.08	0.00
			78.6	37.00	61.40	1.71	0.00
25	5	5	13.1	94.85	0.50	4.89	0.01
			26.2	83.35	12.90	3.95	0.01
			39.3	63.80	33.45	3.01	0.00
			52.4	52.30	45.00	2.43	0.00
			78.6	43.05	54.95	1.99	0.00
25	7.5	10	13.1	94.95	0.30	5.06	0.00
			26.2	91.00	4.90	4.31	0.00
			39.3	72.50	24.30	3.39	0.00
			52.4	61.70	35.75	2.88	0.01
			78.6	49.20	48.40	2.31	0.00
25	8	20	13.1	94.65	0.40	5.22	0.01
			26.2	93.95	1.85	4.55	0.01
			39.3	81.80	14.50	3.86	0.00
			52.4	71.00	25.70	3.33	0.01
			78.6	55.05	42.60	2.58	0.00
25	12	20	13.1	92.45	1.50	6.31	0.01
			26.2	92.55	2.25	5.46	0.00
			39.3	86.70	9.05	4.62	0.00
			52.4	75.85	20.70	3.55	0.01
			78.6	59.35	37.85	2.78	0.00
25	12	30	13.1	93.25	0.70	6.32	0.01
			26.2	93.65	1.20	5.48	0.01
			39.3	89.90	5.60	4.77	0.01
			52.4	79.50	17.00	3.71	0.01
			78.6	62.70	34.55	2.92	0.00
25	16	30	13.1	92.85	1.70	5.76	0.01
			26.2	93.45	1.90	4.95	0.01
			39.3	92.35	3.30	4.59	0.01
			52.4	85.30	10.75	4.13	0.01
			78.6	67.45	29.40	3.24	0.01

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
25	16.5	40	13.1	93.75	0.70	5.80	0.00
			26.2	94.45	0.85	4.97	0.00
			39.3	93.55	2.05	4.61	0.00
			52.4	87.35	8.65	4.18	0.00
			78.6	68.15	28.70	3.26	0.00
25	18	44	13.1	93.65	0.80	5.89	0.01
			26.2	94.40	0.90	5.07	0.01
			39.3	93.95	1.55	4.73	0.01
			52.4	90.25	5.60	4.37	0.01
			78.6	71.70	25.85	3.40	0.00
25	20	20	13.1	92.95	1.45	5.77	0.00
			26.2	93.75	1.70	4.94	0.00
			39.3	92.55	3.15	4.56	0.00
			52.4	86.90	9.10	4.16	0.00
			78.6	68.50	28.25	3.26	0.00
25	22	40	13.1	93.95	0.10	6.26	0.01
			26.2	94.95	0.10	5.31	0.01
			39.3	94.95	0.40	4.93	0.01
			52.4	93.75	1.90	4.64	0.01
			78.6	80.60	15.85	3.87	0.01
25	30	30	13.1				
			26.2	94.55	0.10	5.61	0.00
			39.3	94.95	0.20	5.17	0.00
			52.4	94.95	0.40	4.89	0.01
			78.6	92.70	3.10	4.47	0.01
25	40	40	13.1				
			26.2	94.80	0.50	5.63	0.00
			39.3	94.60	0.60	5.33	0.00
			52.4	94.60	0.60	5.33	0.00
			78.6	94.60	0.80	4.90	0.00
25	44[1]	44[1]	13.1				
			26.2	94.90	0.10	5.81	0.00
			39.3	94.80	0.10	5.43	0.00
			52.4	94.90	0.20	5.22	0.00
			78.6	95.00	0.20	4.98	0.00

[1]Chambers equilibrated at 42,500 ft maximum.

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
40	0	0	13.1	94.65	0.80	4.84	0.01
			26.2	84.20	11.90	3.97	0.01
			39.3	65.30	32.10	3.06	0.00
			52.4	53.50	44.10	2.51	0.00
			78.6	43.60	54.50	2.04	0.00
40	5	5	13.1	94.75	0.40	5.11	0.01
			26.2	92.90	2.90	4.45	0.01
			39.3	78.05	18.50	3.67	0.01
			52.4	64.60	32.20	2.96	0.00
			78.6	50.35	47.05	2.33	0.00
40	7.5	10	13.1	94.75	0.30	5.23	0.00
			26.2	94.25	1.45	4.58	0.00
			39.3	86.05	10.05	4.02	0.00
			52.4	73.10	23.40	3.41	0.01
			78.6	57.70	39.45	2.67	0.00
40	8	20	13.1	94.60	0.40	5.33	0.01
			26.2	94.60	1.05	4.68	0.01
			39.3	90.45	5.55	4.24	0.01
			52.4	80.80	15.65	3.75	0.01
			78.6	61.90	35.70	2.89	0.00
40	12	20	13.1	92.55	1.40	6.44	0.00
			26.2	92.75	1.85	5.68	0.00
			39.3	91.25	3.90	5.18	0.00
			52.4	86.35	9.85	4.03	0.01
			78.6	67.90	29.05	3.18	0.01
40	12	30	13.1	93.05	0.60	6.65	0.01
			26.2	93.60	0.95	5.74	0.01
			39.3	92.45	2.60	5.21	0.01
			52.4	87.95	8.15	4.10	0.01
			78.6	70.70	26.25	3.29	0.00
40	16	30	13.1	92.95	1.60	5.72	0.01
			26.2	93.35	1.80	5.05	0.01
			39.3	93.10	2.50	4.71	0.01
			52.4	90.60	5.30	4.41	0.01
			78.6	76.05	20.45	3.62	0.01

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %[2]	N_2 %[2]	Ar %	CO_2 %[2]
40	16.5	40	13.1	93.85	0.70	5.66	0.00
			26.2	94.35	0.90	5.04	0.00
			39.3	93.95	1.55	4.72	0.00
			52.4	91.90	3.90	4.44	0.00
			78.6	75.90	20.60	3.62	0.00
40	18	44	13.1	93.70	0.80	5.77	0.01
			26.2	94.25	0.90	5.14	0.01
			39.3	94.15	1.35	4.81	0.01
			52.4	92.90	2.85	4.55	0.01
			78.6	78.20	18.20	3.72	0.00
40	20	20	13.1	91.20	3.55	5.54	0.00
			26.2	91.55	3.75	4.96	0.00
			39.3	91.45	4.15	4.63	0.00
			52.4	90.35	5.45	4.39	0.00
			78.6	76.95	19.60	3.63	0.01
40	22	40	13.1	94.15	0.00	6.07	0.01
			26.2	94.85	0.10	5.38	0.01
			39.3	94.95	0.35	5.02	0.01
			52.4	94.50	0.95	4.77	0.01
			78.6	88.35	7.70	4.23	0.01
40	30	30	13.1				
			26.2	94.55	0.15	5.59	0.01
			39.3	94.85	0.20	5.23	0.01
			52.4	94.95	0.35	4.99	0.01
			78.6	94.15	1.50	4.61	0.01
40	40	40	13.1				
			26.2	94.80	0.40	5.39	0.00
			39.3	94.70	0.50	5.38	0.00
			52.4	94.70	0.50	5.30	0.00
			78.6	94.50	0.60	4.97	0.00
40	44[1]	44[1]	13.1				
			26.2	94.80	0.20	5.49	0.00
			39.3	94.70	0.20	5.33	0.00
			52.4	94.70	0.20	5.32	0.00
			78.6	94.80	0.30	5.04	0.00

[1]Chambers equilibrated at 42,000 ft maximum.

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %	N_2 %	Ar %	CO_2 %
60	0	0	13.1	94.65	0.70	4.96	0.01
			26.2	87.50	8.70	4.12	0.01
			39.3	68.60	28.70	3.19	0.00
			52.4	56.20	41.30	2.64	0.01
			78.6	45.20	52.75	2.14	0.00
60	5	5	13.1	94.75	0.40	5.14	0.01
			26.2	93.55	2.20	4.53	0.01
			39.3	82.00	14.30	3.86	0.01
			52.4	67.90	29.00	3.14	0.00
			78.6	53.35	44.60	2.48	0.00
60	7.5	10	13.1	94.75	0.30	5.25	0.00
			26.2	94.45	1.25	4.62	0.00
			39.3	88.65	7.45	4.14	0.00
			52.4	75.55	21.10	3.52	0.01
			78.6	58.90	36.95	2.76	0.01
60	8	20	13.1	94.55	0.40	5.32	0.01
			26.2	94.65	0.95	4.71	0.01
			39.3	91.35	4.60	4.29	0.01
			52.4	83.40	12.95	3.87	0.01
			78.6	63.65	33.50	2.99	0.00
60	12	20	13.1	92.55	1.40	6.35	0.00
			26.2	92.85	1.75	5.69	0.00
			39.3	91.70	3.35	5.20	0.00
			52.4	88.25	7.85	4.12	0.01
			78.6	70.55	26.25	3.30	0.01
60	12	30	13.1	93.45	0.55	6.34	0.01
			26.2	93.75	0.95	5.64	0.01
			39.3	92.85	2.20	5.19	0.01
			52.4	89.35	6.75	4.17	0.01
			78.6	72.60	24.15	3.36	0.01
60	16	30	13.1	93.05	1.55	5.67	0.01
			26.2	93.45	1.75	5.08	0.01
			39.3	93.25	2.35	4.74	0.01
			52.4	91.25	4.60	4.45	0.01
			78.6	78.65	17.65	3.76	0.01

Inlet pressure psig	Cabin altitude kft	Exhaust altitude kft	Flow LPM	O_2 %[2]	N_2 %[2]	Ar %	CO_2 %[2]
60	16.5	40	13.1	93.90	0.75	5.60	0.00
			26.2	94.25	0.90	5.06	0.00
			39.3	94.05	1.45	4.71	0.00
			52.4	92.50	3.30	4.48	0.00
			78.6	77.65	18.80	3.71	0.00
60	18	44	13.1	93.85	0.75	5.72	0.01
			26.2	94.25	0.90	5.16	0.01
			39.3	94.25	1.25	4.85	0.01
			52.4	93.15	2.55	5.60	0.01
			78.6	79.80	16.50	3.79	0.01
60	20	20	13.1	91.15	3.60	5.47	0.00
			26.2	91.50	3.80	4.95	0.00
			39.3	91.45	4.15	4.66	0.00
			52.4	90.45	5.30	4.41	0.00
			78.6	79.55	16.90	3.74	0.01
60	22	40	13.1	94.35	0.10	5.94	0.01
			26.2	94.85	0.15	5.36	0.01
			39.3	94.90	0.40	5.02	0.01
			52.4	94.55	0.95	4.79	0.01
			78.6	89.40	6.60	4.28	0.01
60	30	30	13.1				
			26.2	94.65	0.10	5.56	0.01
			39.3	94.95	0.20	5.23	0.01
			52.4	94.95	0.35	4.98	0.01
			78.6	94.25	1.45	4.62	0.01
60	40	40	13.1				
			26.2	94.90	0.40	5.42	0.00
			39.3	94.80	0.50	5.41	0.00
			52.4	94.80	0.60	5.18	0.00
			78.6	94.90	0.07	4.95	0.00
60	44[1]	44[1]	13.1				
			26.2	94.90	0.20	5.41	0.00
			39.3	94.90	0.20	5.38	0.00
			52.4	94.80	0.30	5.12	0.00
			78.6	94.60	0.40	4.98	0.00

[1]Chambers equilibrated at 42,500 ft maximum.